

Received: 20 November 2023 • Revised: 16 December 2023 • Accepted: 09 January 2024

Research

doi: 10.22034/jcema.2024.426195.1126

Case study of the effect of remain clinker consumption on the technical characteristics of cement and concrete

Ali Akbar Kafash Bazari ^{1*}, Bahar Mirzazadeh ², Zivar Nikfal ³, Mohammad Vatani ⁴, Hamid Gholami ⁴

¹ Chief of research and development of Tehran cement Co, Tehran, Iran.

² Head of Materials Regulation, Chemistry Laboratory and X-Ray of Tehran Cement Industrial Complex.

³ Head of Physics Laboratory of Tehran Cement Co, Tehran, Iran.

⁴ Laboratory expert of Tehran Cement Co, Tehran, Iran.

*Correspondence should be addressed to Ali Akbar Kafash Bazari, Chief of research and development of Tehran cement Co, Tehran, Iran.Tel: (+98) 2133421231; Email: eliaskafash@yahoo.com

ABSTRACT

One of the major concerns of concrete manufacturers is the use of cements resulting from the depot of clinker and remain in cement plants. Depoted clinker is exposed to rain and surface hydration reduces the quality. Therefore, a laboratory operation was designed. During this study, a ton of Portland clinker type 1-425 was prepared and stored in a roofless area. Cementing was performed with a laboratory mill from this clinker at 1 day, 1, 2, 3 and 6 months. For uniformity, fineness was constant in all five cement samples and Blaine index of 3100 ± 100 cm²/gr was considered. Physical tests of cement including blaine, setting time, residue on sieves and strength of mortar were performed on all samples. Concrete mixes with constant slump were also made. At each stage, chemical analysis, microscopic studies and clinker gindability were performed. The results of concrete strength showed that clinker stay for 6 months, a decrease in compressive strength of mortar and 28-day concrete causes about 300%. This comparison for clinker showed that during 6 months the alite phase is reduced by about 14% in chemical analysis and about 40% in microscopic studies. (Due to the small depot volume of this project compared to the actual volumes, these results are quite strict and the use of results must be careful.).

Keywords: Clinker, cement, concrete, remain

Copyright © 2024, Ali Akbar Kafash Bazari. This is an open access paper distributed under the [Creative Commons Attribution License](#). [Journal of Civil Engineering and Materials Application](#) is published by [ISNet](#); Journal p-ISSN 2676-332X; Journal e-ISSN 2588-2880.

1. INTRODUON

It is clear that when the clinker is exposed to the open air, it reacts with moisture (air or rain) and loses its desired properties. According to various resources, the temporary accumulation of clinker should be done in a roofed silo or warehouse. When there is a lot of free lime in the accumulated clinker (weathered clinker), the

results of the cement health test (Autoclave-ASTM C151) should be controlled. If clinker is exposed to moisture, it causes partial hydration. Partial hydration of clinker before wear reduces the strength of cement and increases its setting time. The use of clinkers stored outdoors should not lead to an increase in the LOI of cement by more than

1% and should not consume more than 10% of the clinker feed in Mill. We know that clinker phases play an important role in the development of concrete strength [1-4], therefore if it is unavoidable to store clinker in the open space, it is recommended to first separate grains smaller than 5 mm from the clinker (sieve and) in order to prevent the creation of dust during transportation and also to prevent further hydration of the clinker [5-11]. Mahmoudi et al. (2013) studied 2-year-old clinker compared to fresh clinker. They observed a 20% loss in standard mortar strength and a 5% increase in initial setting time [12]. Lyu et al. (2024) also pointed out the negative effect of clinker free lime on cement strength [13]. According to the study conducted in Urmia Cement (2014) on 1-year-old clinkers, the grindability of the remaining clinker is very low compared to the fresh clinker, and the cement is obtained with inappropriate fineness. The 28-day compressive strength of the standard clinker mortar has a 10% loss in strength compared to the fresh clinker. [14]. Kafash et al. (1400) conducted a rigorous laboratory study on the accumulated clinker and found that the accumulation of 1 ton of clinker in 6 months causes a 300% loss in the compressive strength of the 28-day mortar and concrete [15].

Dubina et al. (2008) studied the effect of pre-hydration of clinker phases on Portland cement characteristics. The degree of hydration refers to the fraction of cement that has completely reacted with water compared to the total cement in the sample [16]. Using different analyses, they showed that the Alite phase is sensitive to humidity and in high humidity (>85%), water molecules are absorbed on the surface. For the steps before hydration, the time for water to reach the remaining C3S clinker is longer than that of the fresh C3S samples [17]. Usually, the increase of free lime in cement indicates pre-hydrated (or raw) clinker. Faraz et al. (2023) evaluated the rheological properties of pre-hydrated Portland cement and concluded that the pre-hydrated sample had a lower shear stress level than the reference sample, because the non-hydrated sample has a higher reactivity [18]. Rikert (2019) investigated the effects of the remaining clinker from the perspective of chemical-microscopic

properties and how to neutralize possible negative effects [19]. Mtarfi et al. (2017) indirectly investigated the residual clinker by monitoring the effect of clinker free lime on the physicochemical properties of cement. Their results showed that physical characteristics such as normal concentration and water demand are affected by free lime and cause faster setting, lower compressive strength (especially at young ages) and higher expansion (autoclave) of cement [20]. Uchikawa et al. (1983) also obtained similar results in this field [21]. Mohanu et al. (2010) studied the effects of clinker storage in inappropriate conditions and its consequences on cement performance with chemical and mineralogical investigations (X-ray diffraction, optical microscopy) [22].

Clinker size is important to optimize grinding and cement quality. The increase of coarse or fine clinker grains can lead to grinding hardness and have a negative effect on cement performance, which is usually for free lime (1-2%) and aggregates (less than 25% passing through a 1 mm sieve and less than 25% remaining on a sieve of 25 mm) is a suitable target range [23]. Coarse clinker nodules are more problematic for ball mills, but fine clinker grains are less problematic in ball mills because these particles simply pass through the first chamber, although they can reduce the crushing effect of this chamber somewhat. However, finer clinker grains can lead to harder grinding; Therefore, the goal is to limit clinker particles smaller than 1 mm to less than 25% in ball mills [24]. It seems that in the remaining clinkers (deposited in a space without a roof) due to hydration (blooming of coarse grains or sticking and hardening of fine particles to each other), the optimal grading of clinker is lost, which leads to improper cement grading. It has not been conclusively proven that the grindability of weathered (or stored) clinker is significantly different from fresh clinker.

Usually, clinker is stored in the open air for 1-4 months; When the fineness and specific surface are the same, the amount of free lime decreases with increasing time, the setting time becomes longer and the bending and compressive strength decreases (Fig1) [25].

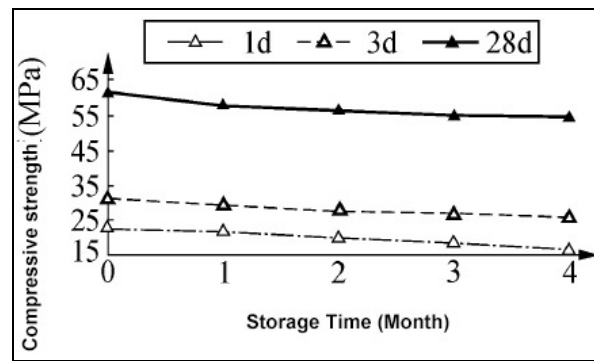


Figure 1. Investigating the relationship of clinker retention on the compressive strength of standard mortar for 4 months [25]

Examining various resources and studies shows that the effect of mixing fresh and weathered clinker in cement and its performance in concrete has not been studied. Due to the limitations of clinker production, it is common to use accumulated clinkers. The purpose of this study project is to investigate the

effect of using different amounts of weathered clinker in cement and concrete so that appropriate information can be provided for cement producers and consumers in order to optimize the execution conditions in concreting.

2. MATERIALS AND METHODS

The laboratory program of this study was as follows (Figure 3):

1) Preparation of about 1ton of fresh Portland type II clinker samples.

2) Preparation of about 1 ton of type II Portland clinker sample, which remains for 2 years (accumulation).

3) Preparation of 1 gypsum sample and its analysis (Table1).

Table 1. Chemical analysis of gypsum used in laboratory cementing

Molecular water	CaSO ₄	SO ₃	MgO	CaO	Fe ₂ O ₃	Al ₂ O ₃	SiO ₂
18.42	70.6	41.54	0.78	31.8	0.22	0.78	1.84

4) Conducting a microscopic study on clinker samples (Table2); (These results show that the

clinker Alite gradually decreases and turns into billet and free lime).

Table2. Summary of the results of microscopic studies of clinker samples used in cement making

Peri clase clusters (μ)	Belite clusters (μ)	C2S (μ)	C3S (μ)	Priclese (%)	Free lime (%)	C ₄ AF (%)	C ₃ A (%)	C ₂ S (%)	C ₃ S (%)	Type
No	154	21	20	0/0%	1/2%	17%	6%	11%	65%	Fresh
No	167	19	20	0/4%	13/2%	18%	3%	34%	30%	Depot

5) Cementing according to Table 3 with the criterion of reaching the Blaine index of 300±10 m²/kg.

Table 3. Composition of laboratory cements

Depot clinker	Fresh clinker (%)	Gypsum	Name of cement (amount of clinker depot□
0	95	5	D-0%
10	85		D-10%
25	70		D-25%
47.5	47.5		D-50%
95	0		D-100%

- 6) Measuring the electrical energy consumed for grinding of 5 cement samples.
- 7) Determination of chemical characteristics (XRF, determination of free lime and LOI), physical and mechanical characteristics of cements (retained on sieves, Blaine, setting time, normal consistency and compressive strength of standard mortar).

- 8) Preparation of concrete mixture without additives to achieve a slump of 8 ± 0.5 cm, performing slump loss tests, determination of fresh concrete air, density, intuitive characteristics of fresh concrete and compressive strength (Figure 2).



Figure 2. Views of laboratory operations

Figure 3 and Table 4 show the characteristics of aggregates used in this study. The optimal use of coarse aggregates [6 and 26] was considered.

Table 4. Characteristics of stone materials used in concrete mixtures

Type	MSA	fineness modulus (FM)	Water absorption (%)	ρ (SSD)	Fracture (%)	Passing percent of sieve 200
gravel	25	7.5	2.12	2.53	66	0.6
sand	*	3.8	3.18	2.55	*	3.1

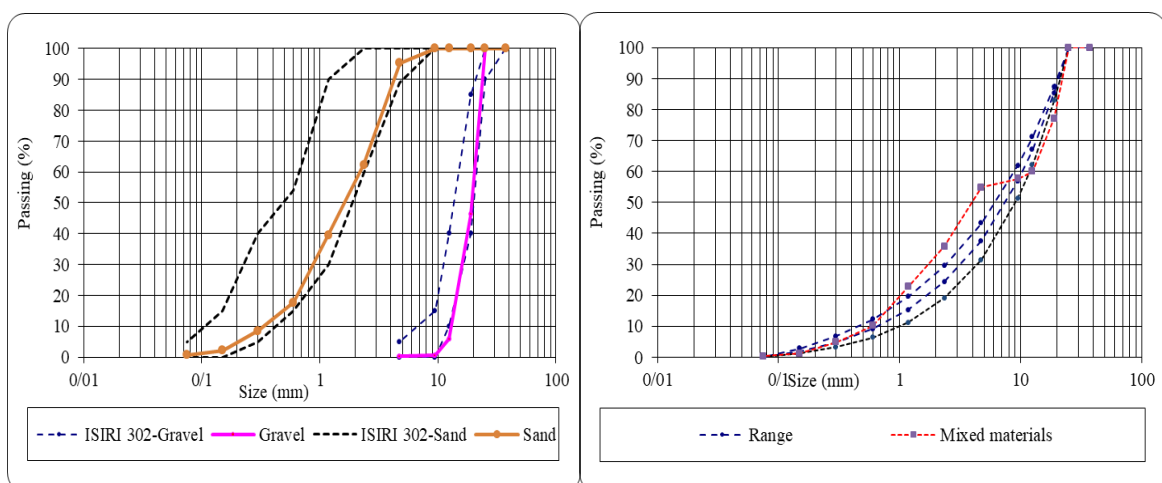


Figure 3. Grading diagram of aggregates and mixture

In the mix design of concrete, the corresponding power in the Fuller-Thomson relationship $n: 0.35$ was considered (Figure3 and Table 5) [27]. In this project, the basis of preparation of laboratory concrete mixtures was to achieve proper

performance (slump 8.0 ± 0.5 cm), which was obtained ~ 0.54 w/c. The grade of cement in all designs was 350 kg/m^3 . The compressive strength of the samples was measured at the age of 7, 28 and 90days.

Table 5. general characteristics of concrete mix designs

w/c	Weight amount (kg/m^3)			
	water	cement	gravel	sand
0.54	190	350	740	1000

3. RESULTS AND DISCUSSION

[Table 6](#) shows the results of chemical analysis of cement samples by XRF method, which shows their similarity.

Table 6. Results of chemical analysis of cement samples by XRF method

Sample Name	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	SO ₃	K ₂ O	LSF	SIM	ALM	C ₃ S	C ₂ S	C ₃ A
D-0%	20.77	4.25	3.87	62.63	3.80	2.59	0.62	92.6	2.56	1.10	55.6	17.6	4.7
D-10%	20.68	4.16	3.78	62.19	3.69	2.41	0.63	92.7	2.60	1.10	55.7	17.3	4.6
D-25%	20.56	4.41	3.84	62.20	3.66	2.71	0.61	92.4	2.49	1.15	54.0	18.2	5.2
D-50%	20.46	4.33	3.89	61.98	3.60	2.67	0.63	92.6	2.49	1.11	54.5	17.6	4.9
D-100%	20.67	4.38	3.84	62.81	3.66	2.81	0.63	92.8	2.51	1.14	55.6	17.3	5.1

In [Figure 4](#), the amount of electrical energy required for the grind of cement was investigated. As can be seen, with the increase of accumulated clinker, the electrical energy required for cement grinding

increases; So that with an increase of about 10% of accumulated clinker, the electrical energy required for grinding of cement increases by about 1 KWhr/ton.

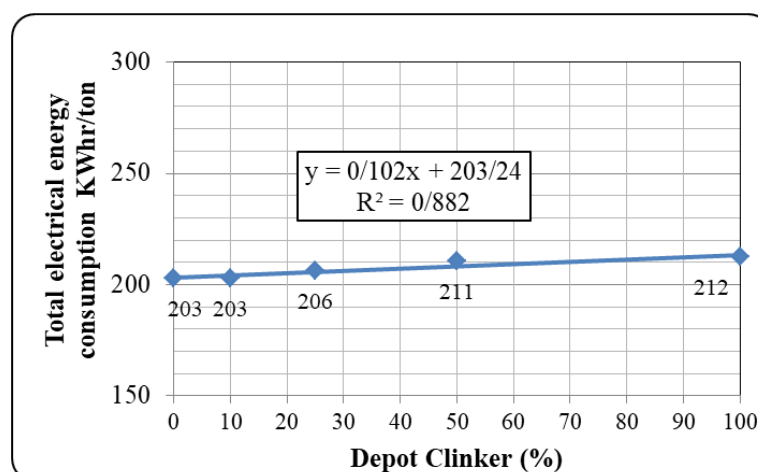


Figure 4. Chart of electrical energy consumption in laboratory cement

[Table 7](#) summarizes the results of determination of free lime, thermal conductivity (LOI) and physical-

mechanical characteristics of 5 manufactured cement samples.

Table7. Summary of the results

No.	LOI (%)	Free lime (%)	Compressive Strength-Mortar (MPa)			Retained on sieve (%)		Blaine (m2/kg)	Setting Time (min)		Normal consistency (%)
			2 Days	7 Days	28 Days	90μ	45μ		Initial	Final	
D-0%	1.41	0.98	25.6	42.9	54.6	1.18	9.08	297.3	200	275	24.0
D-10%	1.56	0.98	23.6	40.4	54.0	1.72	9.44	299.0	205	280	24.0
D-25%	1.66	0.98	20.9	39.9	50.4	1.10	10.60	299.9	240	325	23.5
D-50%	1.82	0.84	21.2	36.2	47.9	1.40	10.80	297.5	245	320	23.5
D-100%	1.79	0.84	20.8	33.0	47.9	1.80	11.40	297.3	240	320	23.5

As can be seen, the results obtained in the experiments to determine the fineness by the Blaine method and the residue on the 90- and 45-micron sieves for all 5 cement samples are similar and indicate the uniformity of grind of the samples (one of the objectives of the laboratory operation). The results of the amount of free lime in the cements were very close to each other, and the values of LOI increase with the increase in the amount of clinker

remaining in the cement (direct relationship); But this increase is not significant and the resulting values (even in the sample containing 100% clinker) are within the standard limit ($>3\%$) [28]. In order to accurately investigate the effect of cumulative clinker consumption on the compressive strength of standard mortar and the setting time of cement paste (using Vicat's method [29]), the diagram of Figure 5 was drawn.

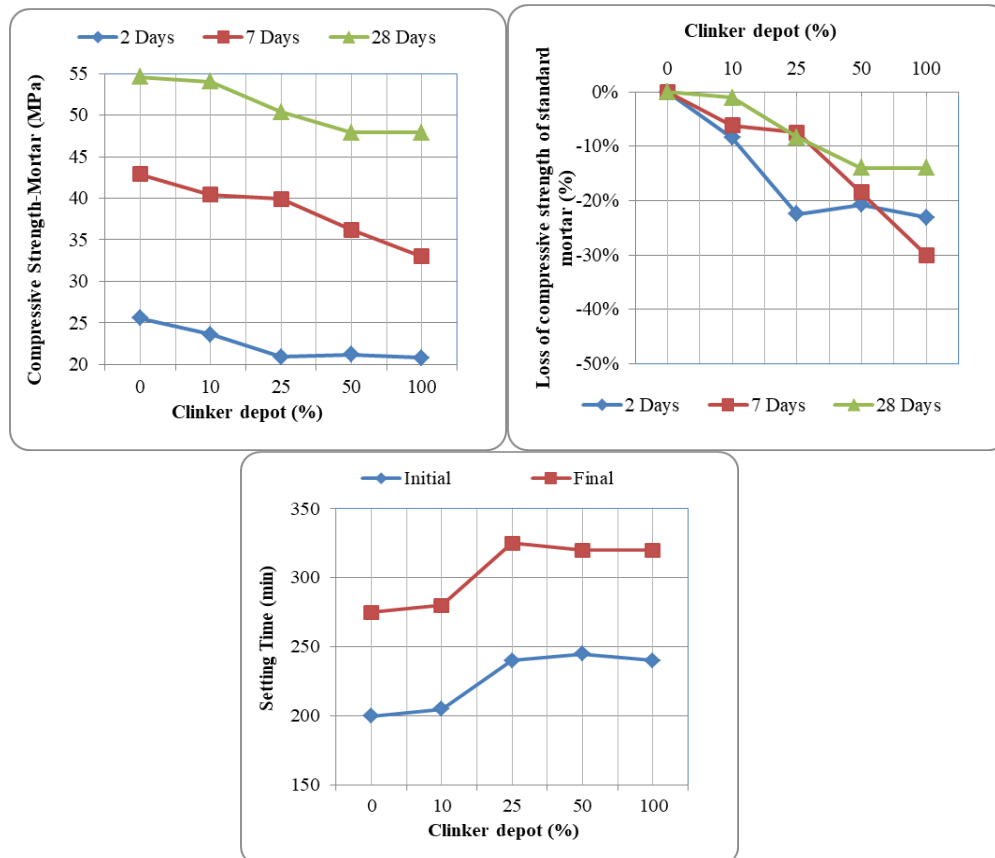


Figure 5. Diagram of the influence of Depot clinker consumption on the compressive strength of standard mortar and cement setting time

According to these results, with the consumption of 10%, 25%, 50% and 100% Depot clinker in cement, respectively 8%, 22%, 21% and 23% loss in compressive strength in 2-day standard mortar and also 6%, 8%, 19% and 30% loss in compressive strength is observed in standard 7-day mortar; In the same way, 1%, 8%, 14% and 14% decrease in the compressive strength of the 28-day standard mortar is observed.

Based on the results of the test to determine the setting time by the Vicat method, with the use of 10%, 25%, 50% and 100% Depot clinker in cement, the initial setting time increases by 5, 40, 45 and 40 minutes, respectively, and 5, 50, 45 and 45 minutes increase the duration of the final setting of cement.

Table 8 summarizes the results of the use of depot clinker on the compressive strength of laboratory concrete mixtures.

Table8. Summary of the results of making laboratory concrete mixes

No	Initial Slump (cm)	Slump 30 minutes (cm)	Air content (%)	w/c	Compressive strength of concrete (MPa)		
					7 Days	28 Days	90 Days
D-0%	8.0	7.0	1.2	0.57	22.7	32.9	34.9
D-10%	8.0	7.0	1.2	0.56	21.5	31.9	32.5
D-25%	8.0	6.5	1.5	0.51	19.6	30.0	31.1
D-50%	8.0	5.0	2.0	0.50	17.6	28.4	29.8
D-100%	8.0	3.0	2.3	0.49	15.7	26.9	28.8

For a detailed analysis, the diagram of the influence of depot clinker consumption on the compressive

strength of concrete was drawn in [Figure 6](#).

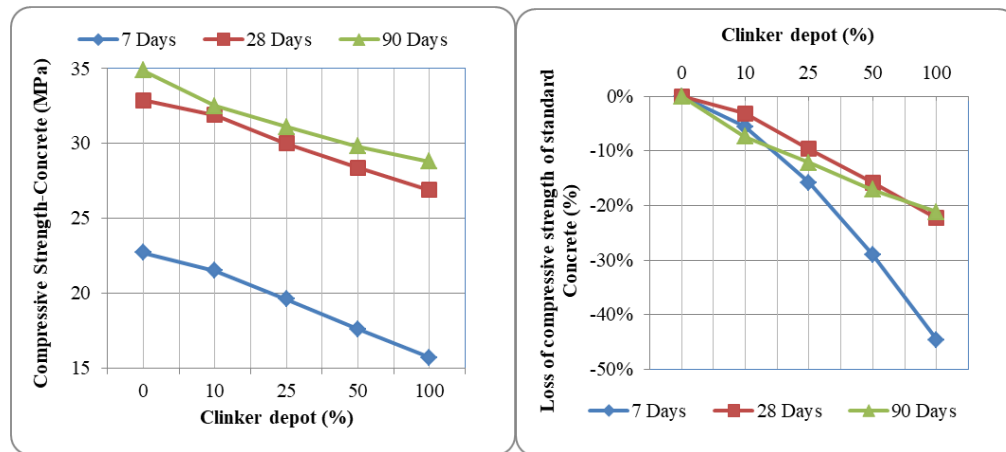


Figure 6. Diagram of the influence of depot clinker consumption on the compressive strength of concrete

The results of concrete mixtures also showed that with increasing amount of clinker remaining (accumulation) in cement:

1-The evaluation and interpretation of the compressive strength results showed that if the clinker depot in the cement increases, the need for water to prepare the concrete mix with the same workability (slump 8 cm) decreases. It seems that the role of reducing the need for water (at a fixed cement grade leading to a decrease in the water-cement ratio) to achieve the same workability in the mixtures has a significant effect on the loss in compressive strength, which is not observed. The reason is that there are particles in the cement obtained from clinker that are hydrated, so they do not play a role in the formation of C-S-H gel, but like fine particles (sand), it increases the workability of concrete and reduces the need for concrete water. Therefore, in total, the ratio of water to cement and the compressive strength of concrete decreases.

2-The initial slump was the same in all concrete mixes, but in the concrete mixes made with cement containing clinker depot, the amount of concrete slump after 30 minutes was very low, and it

indicates the decrease in the time of maintaining workability of concrete. Therefore, the process of slump loss over time becomes unfavorable with the consumption of more clinker depot.

3-In the same way, the air content in fresh concrete also increases with the increase in the amount of clinker depot in the cement, which is inappropriate.

4-If the content of the clinker depot in the cement increases, the compressive strength has a clear decrease, so that with the consumption of 10%, 25%, 50% and 100% of the clinker depot in the cement, respectively 6%, 16%, 29% and 45% loss in compressive strength is observed in 7-day concrete; Similarly, 3%, 10%, 16% and 22% decrease in compressive strength of 28-day concrete is observed; Also, the reduction of the compressive strength of the 90-day concrete results was 7%, 12%, 17% and 21%, respectively;

In general, it can be said that the effect of using clinker depot in reducing the results of short-term compressive strength is greater than the effect of using cumulative clinker in reducing the results of medium-term compressive strength (both in standard mortar and in concrete).

4. CONCLUSION

In total, this study showed that with the increase of the clinker depot content in the cement, the following are observed:

- 1- The grindability becomes unfavorable and the electrical energy required grinding the cement increases, so that with an increase of

about 10% of the clinker depot, the electric energy needed to grind cement increases by about 1 KWhr/ton.

- 2- The values of LOI increase with the increase in the amount of clinker depot in the cement; But this increase is not

significant, and the resulting values are within the standard range (>3%).

- 3- By using 10%, 25%, 50% and 100% clinker depot in cement, the initial setting time increases by 5, 40, 45 and 40 minutes, respectively.
- 4- The process of slump loss within 30 minutes is accelerated by increasing the consumption of clinker depot, and the air content in fresh concrete also increases, both of which are inappropriate.
- 5- According to the results of this study, by using 10%, 25%, 50% and 100% clinker depot in cement, respectively 1%, 8%, 14%

and 14% reduction in compressive strength of 28-day standard mortar and 3%, 10%, 16% and 22% decrease in compressive strength of 28-day concrete is observed.

- 6- The effect of using clinker depot in reducing the results of short-term compressive strength (mortar and concrete) is greater than the effect of using clinker depot in reducing the results of medium-term compressive strength.

FUNDING/SUPPORT

Not mentioned any Funding/Support by authors.

ACKNOWLEDGMENT

We feel it necessary to give special thanks to the managers, experts and respected technicians of the laboratories of Tehran Cement Industrial Complex and other personnel of that complex.

AUTHORS CONTRIBUTION

This work was carried out in collaboration among all authors.

CONFLICT OF INTEREST

The author (s) declared no potential conflicts of interests with respect to the authorship and/or publication of this paper.

5. REGERENCES

- [1] Kafash Bazari AA, Chini M, Nikfal Z, Vatani M. Effect of clinker phase changes on cement performance and its reactivity with super plasticizer additive. Journal of Civil Engineering and Materials Application. 2021 Dec 20;5(4):211-21. [\[View at Google Scholar\]](#); [\[View at Publisher\]](#).
- [2] Turkoglu M, Bayraktar OY, Benli A, Kaplan G. Effect of cement clinker type, curing regime and activator dosage on the performance of one-part alkali-activated hybrid slag/clinker composites. Journal of Building Engineering. 2023 Jun 1;68:106164. [\[View at Google Scholar\]](#); [\[View at Publisher\]](#).
- [3] Krivorodov Y. Cement quality in thermochemical clinker activation. InE3S Web of Conferences 2023 (Vol. 402, p. 07002). EDP Sciences. [\[View at Google Scholar\]](#); [\[View at Publisher\]](#).
- [4] Müller C. Clinker-efficient cements and their application-today and tomorrow. ce/papers. 2023 Dec;6(6):114-26. [\[View at Google Scholar\]](#); [\[View at Publisher\]](#).
- [5] Yousefi, F. Mahmoudi, M. "Cement Factory Management". Publications of the entrepreneurs of construction industry. (2013).
- [6] Philip A Alsop & Hung Chen & Arthur L Chin-Fatt & Andrew J Jackura & Michael I McCabe & Herman H Tseng. (2001). "Cement Plant Operation Handbook: for dry process Plants". [\[View at Publisher\]](#).
- [7] Jensen OM. Clinker mineral hydration at reduced relative humidities. (1998). [\[View at Google Scholar\]](#); [\[View at Publisher\]](#).
- [8] Neville AM, Brooks JJ "Concrete Properties". Prentice Hall. (2002).
- [9] Neville AM, Brooks JJ. Concrete technology. England: Longman Scientific & Technical; 1987 Mar.[\[View at Google Scholar\]](#); [\[View at Publisher\]](#).
- [10] Duda, w. "Cement data book". Volume 2. (1976).
- [11] Kafash Bazari AA, Chini M, Nikfal Z. A Case Study of the Effect of Clinker Microstructural Changes with the Help of Microscopic Studies on the Technical Characteristics of Cement and its Performance in Concrete. Journal of Concrete Structures and Materials. 2022 Dec 22;7(2):131-43. [\[View at Google Scholar\]](#); [\[View at Publisher\]](#).
- [12] Mahmoudi, S. Zarekar, H. "Providing practical tips when using clinker depot". Cement Technology Scientific-Specialist Monthly, 2015, Vol. 98, Pages 53-49 (2015).
- [13] Lyu X, Chu D, Lu X, Mu J, Zhang Z, Yun D. Quality Control of Cement Clinker through Operating Condition Classification and Free Calcium Oxide Content Prediction. Applied Sciences. 2024 Jan 29;14(3):1119. [\[View at Google Scholar\]](#); [\[View at Publisher\]](#).
- [14] Jennett, M. "Surplus production of clinker and the decline of its quality properties in the field" Cement and Additives Monthly, 12th year, number 37 (72, July 2014). Pages 95-100.
- [15] Kafash Bazari, A. Nikfal, Z. Mirzazadeh, b. Vatani, M. Gholami, H. (2023). "Effect of open-air storage on clinker quality". ICR (International cement review), October 2023.
- [16] Fagerlund G. Chemically bound water as measure of degree of hydration: method and potential errors. (2009). "Chemically bound water as measure of degree of hydration: method and potential errors". (Report TVBM; Vol. 3150). Division of Building Materials, LTH, Lund University. [\[View at Google Scholar\]](#); [\[View at Publisher\]](#).
- [17] Dubina E, Sieber R, Planck J, Black L. Effects of pre-hydration on hydraulic properties on Portland cement and synthetic clinker phases. InCement and Concrete Science: Proceedings 2008. Cement and Concrete Science. [\[View at Google Scholar\]](#); [\[View at Publisher\]](#).
- [18] Ferraz DF, Martho AC, Burns EG, Romano RC, Pileggi RG. Effect of prehydration of Portland cement on the superplasticizer consumption and the impact on the rheological properties and

chemical reaction. Revista IBRACON de Estruturas e Materiais. 2022 Sep 19;16(2):e16210. [\[View at Google Scholar\]](#); [\[View at Publisher\]](#).

[19] Rikert "The effects of residual clinker in terms of chemical / microscopic properties and how to neutralize possible negative effects". VDZ. Federal ministry for economic affairs and energy. (2019) .

[20] Mtarfi NH, Rais Z, Taleb M. Effect of clinker free lime and cement fineness on the cement physicochemical properties. J. Mater. Environ. Sci. 2017;8(7):2541-48. [\[View at Google Scholar\]](#); [\[View at Publisher\]](#).

[21] Uchikawa H, Ogawa K, Uchida S. Influence of character of clinker on the early hydration process and rheological property of cement paste. Cement and Concrete Research. 1985 Jul 1;15(4):561-72. [\[View at Google Scholar\]](#); [\[View at Publisher\]](#).

[22] Ileana Mohanu & Nicoleta Vlad & George Stanciu & Roxana Fechet (2010). "Influence of conditions and period of storage for clinker and granulated furnace slag on cement characteristics". Revista Romana de material, Romanian journal of materials, January 2010, RRM 40(2):91-101. [\[View at Google Scholar\]](#); [\[View at Publisher\]](#).

[23] Alsop PA. Cement plant operations handbook: for dry process plants. Tradeship Publications Ltd; 2007. [\[View at Google Scholar\]](#); [\[View at Publisher\]](#).

[24] Bond FC. Grinding ball size selection. Mining Eng.. 1958;10:592-5. [\[View at Google Scholar\]](#); [\[View at Publisher\]](#).

[25] "The effect of Open Storage on Chemical and Mechanical performance" from: [\[View at Publisher\]](#).

[26] ACI 211-1-91 Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concret." (Reapproved 2002) [\[View at Google Scholar\]](#);

[27] Guide to the National Concrete Mix Design Method" Iran Construction and Housing Research Center, p. 33.

[28] ISIRI 389 "Characteristics of Portland cement", Iran Standard and Industrial Research Institute. (2019).

[29] ISIRI 389 "Cement determination of setting time of hydraulic cement with Vicat needle-test method", Iran Standard and Industrial Research Institute (2021).